STRUCTURAL EQUATION MODELLING AND SYSTEM DYNAMIC IN THE DETECTION OF POWER QUALITY EVENTS

ASHRAF ZULFA BINTI AZIZAN

A thesis submitted in partial

fulfillment of the requirement for the award of the

Degree of Master of Electrical Engineering

Faculty of Electric and Electronic Engineering

Universiti Tun Hussein Onn Malaysia

JANUARY 2012

ABSTRACT

The issues of power quality had been discussed since the starting of power system and it will keep on arise from time to time because power quality is important to electricity consumers at all levels of usage. Since sensitive equipments and power electronic devices are now more common in industrial/commercial sectors as well as domestic use, the awareness of power quality is developing amongst electricity users. In general, the main power quality issues can be identified as voltage variations, voltage imbalance, voltage fluctuations, transients, harmonic distortions, interruptions, etc. The consequences of one or more of the above non-ideal conditions may cause thermal effects, life expectancy reduction, dielectric strength reduction and disoperation of different equipments. In this project, power quality events are verified using Structural Equation Modeling (SEM) and System Dynamic method. In detecting power quality events, Amos 5.0.1 and Vensim PLE for Windows version 5.11 were used. The verification of power quality events involves identification, classification and mitigation process on several power quality events that occurred in electrical power system.

ABSTRAK

Isu-isu tentang kualiti kuasa telah dibincangkan semenjak bermulanya sistem kuasa dan ia akan terus dibangkitkan dari masa ke semasa kerana kualiti kuasa adalah penting kepada pengguna-pengguna bekalan elektrik pada semua tahap penggunaan. Disebabkan peralatan-peralatan sensitif dan juga peralatan elektronik kuasa semakin biasa digunakan di dalam sektor industri atau komersial serta kegunaan domestik, kesedaran tentang kualiti kuasa berkembang di kalangan pengguna-pengguna bekalan elektrik. Secara amnya, isu utama kualiti kuasa boleh dikenalpasti melalui variasi voltan, ketidakseimbangan voltan, naik-turun voltan, transien, pengherotan harmoni, gangguan dan sebagainya. Akibat daripada satu atau lebih daripada keadaan-keadaan tidak ideal seperti yang di atas boleh menyebabkan kesan terma atau kepanasan, pengurangan jangkahayat, pengurangan kekuatan dielektrik dan ketidakfungsian peralatan. Di dalam projek ini, gangguan kualiti kuasa disahkan menggunakan kaedah *Structural Equation Modeling (SEM)* dan *System Dynamic.* Dalam mengesan gangguan kualiti kuasa, perisian AMOS 5.0.1 dan Vensim PLE for Windows Version 5.11 digunakan. Pengesahan gangguan kualiti kuasa melibatkan proses pengenalpastian, pengelasan dan penyelesaian kepada beberapa gangguan kualiti kuasa yang berlaku di dalam sistem kuasa elektrik.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

LISREL	-	Linear Structural Relations
SEM	-	Structural Equation Modeling
RL	-	Resistor-Inductor
ADALINE	-	Adaptive Linear Neuron
DC	-	Direct Current
CBEMA	-	Computer Business Equipment Manufacturing Association
ANSI	-	American National Standards Institute
ITIC	-	Information Technology Industry Council
PQ	-	Power Quality
TNB	-	Tenaga Nasional Berhad
RPM	-	Reliable Power Meter
THD	-	Total Harmonic Distortion
RMS	-	Root Mean Square

CHAPTER 1

INTRODUCTION

1.1 Project Introduction

Structural equation modeling is an extension of the general linear model that enables researchers to fit more than one regression equation simultaneously [1]. It encompasses a larger number of statistical procedures including latent variable analysis, confirmatory factor analysis, causal modeling, LISREL analysis, growth curve modeling, etc. Structural equation modeling possess several advantages which includes the incorporation of latent variables can significantly reduce measurement error. In other words, the more indicators you have for a factor the better graphical modeling interface. [2]. The primary purpose of SEM rests in the adequacy of a predetermined theoretical model to explain relationships among observed variables and/or unobserved variables [3]. By far, the strongest argument in support of SEM is the need for researchers to explicitly state a priori causal theory. SEM has the availability of tests of 'Global Model Fit' and the ability to include multiple outcome variables [4]. The advantages of SEM also include the ability to model error terms and the ability to test coefficients across multiple groups [5].

System dynamics is an approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system [6, 7]. In another word, system dynamic is a methodology and mathematical modeling technique for framing, understanding, and discussing complex issues and problems [8]. System dynamics has been used extensively to aid in resource planning in the electric power industry. The many applications constitute a major body of work that has proven useful to large and small power companies as well as to government agencies at the local, state and federal level. The work has been performed by utility analysts, government planners, consultants and academics. System dynamics was first used in water resource planning in the study of river basin development. With that start, more research on system dynamic has been carried out [9, 10].

This project will use these two methods in an attempt to detect power quality events such as harmonics and voltage sags that occurred in electric power system. With all the steps in both methods, the data will be analyzed and thus, detecting the events and the possible mitigation will then be justified.

1.2 Problem Statement

Poor power quality may cause electrical appliances malfunction or fuses to trip. When a disturbance occurs, huge financial losses may happen, with the consequent loss of productivity and competitiveness. This project was done to analyze, identify and classify the power quality events such as voltage sags and harmonics in electrical power system using structural equation modeling and system dynamic modeling because sometimes, it is hard to detect the events using the typical software used. So by using these two methods, it might be a solution to easily detect the power quality events. From that, a comparison between structural equation modeling and system dynamic modeling will take position thus suggesting a possible mitigation for a better performance of electrical energy supply.

1.3 Objective of Project

There are a few objectives for this project that includes:

1. To implement structural equation modeling and system dynamic method in electrical power system.
2. To determine several power quality events in electrical system using the methods mentioned.
3. To propose a possible mitigation for the power quality events occurred.

1.4 Scope of Project

Every project has its scope and limitation. For this particular project, the scopes and limitation are:

1. This project only focused on two power quality events, which are voltage sags and harmonics.

2. The techniques use to identify the power quality events are only structural equation modeling and system dynamic.

Based on problem statement, objective and scope, the project was done step by step from the literature review and methodology until the final results and conclusion. The literature review, which contains the previous studies related to this project, is explained in next chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Electrical fault in a distribution network is almost impossible to avoid. Main causes for power quality disturbances may be due to insulation failure, tree falling, bird's contact, lightning or a fault on an adjacent feeder [11]. The research of power quality issues has captured ever increasing attention in the power engineering society [12]. A power quality problem can be described as any variation in the electrical power service, such as voltage sags and swells, interruptions, transients, harmonics, notches, and fluctuations, resulting in misoperation or failure of end-use equipment. To analyze these electric power system disturbances, data is often available as a form of a sampled time function that is represented by a time series of amplitudes [13].

According to Dogan Gokhan Ece and Omer Nezih Gerek [14], by using Joint 2-D-Wavelet Subspaces in detecting power quality events, good detection of power quality events than one-dimensional discrete wavelet transform is provided. This method also has more operational flexibility because of the available image processing tools. The test was applied on the voltage waveforms from real life power quality events captured at

20kHz from an experimental system, which is composed of a three-phase wye-connected 380V, 50Hz, 25kVA, 5-wire supply loaded with RL load banks and three-phase induction motors coupled with varying mechanical loads. The system also includes adjustable speed drives that control the induction motor. Another advantage is this method does not experience short discontinuity at the beginning and the end of the events. Although this method provides good detection of power quality events, it is difficult to observe the data if it is only processed in horizontal direction. This means that by using this method, the data have to be processed in both horizontal and vertical direction in order to easily observe the result.

Carlos A. Duque, Moises V. Ribeiro, Frederico R. Ramos and Jacques Szczupak [15] have published a journal in detecting power quality events based on the Divide and Conquer Principle and Innovation Concept. The power quality events detection is based on the Divide and Conquer Principle and Innovation Concept, as found in Kalman's filter formulation, and it is applied to voltage signals. This method makes use of digital signal processing techniques to obtain the stationary and non-stationary components of the monitored power quality events. The Innovation Concept is implemented to detect power quality disturbances start and end point. There are a few advantages of this method which are it introduces a simple and efficient way to evaluate the total harmonic distortion, in case of harmonic pollution, this method offers a new perspective in analyzing power quality events or even other problems in the power systems and by using this method, more accurate detections of power quality events can be accomplished. There is only one disadvantage of this method which is it requires a much reduced computational complexity for event detection, as compared to usual procedure. This means that this method cannot be used in a complex situation.

In analyzing power quality events, Dogan Gokhan Ece and Omer Nezih Gerek [16] used Higher Order Cumulants and Quadratic Classifiers method. This method uses higher order cumulants as the feature parameter and quadratic classifiers to classify the power quality events. The events investigated are line-to-ground arcing faults and voltage sags due to the induction motor starting. A vector with six parameters is used as a feature vector. After the detection of power quality events, the maximum and minimum values of the cumulants around the event instant are used to classify the events. The conclusions made from the experiment done are higher order statistics are effective tools to detect deviations from Gaussianity, which is valid for several types of different loading conditions, the combination of higher order statistical parameters and quadratic classifiers is a promising tool for power quality event detection and classification and the cumulant calculation can be performed in real time even using simple microcontrollers even though for power quality event discrimination, using lower order cumulants is not possible as the complicated fluctuations cannot be visualized or differentiated [16].

Cheng-I Chen and Yu-Ting Fu [17] uses Wavelet and Adaptive Linear Combiner (ADALINE) to detect power quality events in 2010. By using this method, power system monitoring provides accurate and useful information to power grids and the starting and ending time of events can be effectively detected. On the conference paper, it was stated that power quality events are detected and classified by combining the wavelet analysis and adaptive linear combiner (ADALINE). The proposed algorithm is demonstrated by a simple laboratory setup with LabVIEW program and actual recorded waveforms. By using Wavelet and Adaptive Linear Combiner (ADALINE), time location of events can be detected more accurately than the traditional window-based methods and adaptive filtering techniques. But this method requires many computational operations and need data training and the adaptive approaches always suffer from numerical stability and computational burden.

Also, in the year 2010, Dr.M.Sushama, Dr.G.Tulasi Ram and Dr.A.Jaya Laxmi [18] used Wavelet Transforms in detecting power quality disturbances. Wavelet transform is used to identify the power quality disturbances at its instance of occurrence.

The power quality events considered are sag, swell, interruption, DC offset, frequency variation and harmonics. For this method, it is fast, sensitive and practical for detection and identification of power quality disturbances and it is suitable for stationary signal analysis where frequency component doesn’t vary with time. The wavelet method can also be applied in other fields due to its variety of properties such as astronomy, nuclear engineering, acoustics, signal and image processing, speech discriminations, radar, human vision and in mathematics applications such as solving partial differential equations.

On every existing approach to compensate for voltage disturbances, the very first step is to detect the disturbance itself, and then other actions will come such as compensation or disconnection [19]. For this project, the power quality event was detected first using Power Analysis Software. After that, the analysis using Structural Equation Modeling and System Dynamic methods were done. The explanations on every method were discussed in Chapter 3.

CHAPTER 3

METHODOLOGY

3.1 Introduction

For the methodology of this project, it consists of five phases. The first phase is literature study of Structural Equation Modeling and System Dynamic methods. In this phase, the problem of Power Quality events is identified. The project will be followed by the second phase which is data collection. After the data is collected, the third phase of this project starts with the evaluation of the data using the first method as stated in the project title and also the flow chart given below. The methodology phase continues with the phase four which is the evaluation of the data using the second method and the last phase of this project is comparing the results of the two methods used, thus suggesting which one is the best method in detecting power quality events. Figure 3.1 below shows the flow chart of the project.

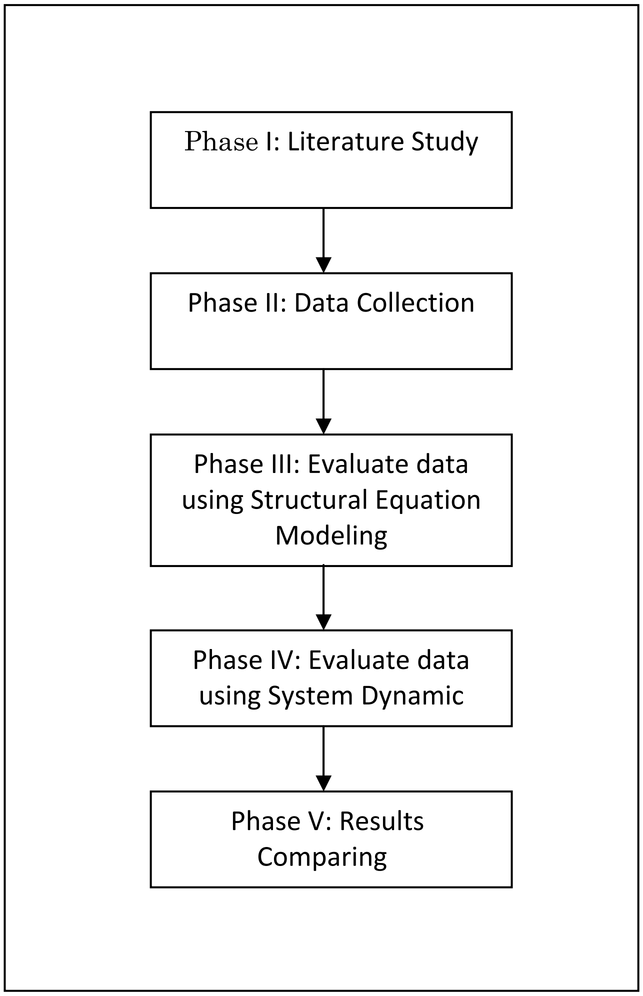


Figure 3.1: Block Diagram of Methodology

3.2 Phase I: Literature Study

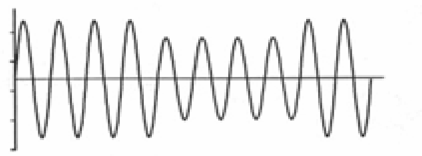
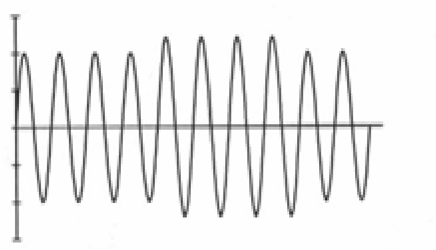
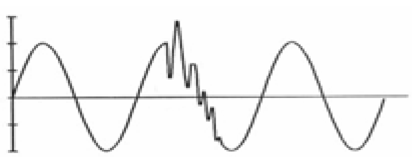
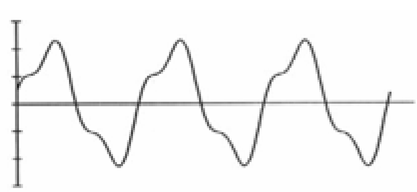
Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, it should be mean that the electrical power is of good quality. On the other hand, if the electrical equipment malfunctions, is unreliable, or is damaged during normal usage, it indicates that the power quality is poor. The power quality can be verified by installing a special type of high-speed recording test equipment to monitor the electrical power. This type of test equipment will provide information used in evaluating if the electrical power is of sufficient quality to reliably operate the equipment.

Power quality events can be defined as any power problem manifested in voltage, current or frequency deviation. There are several problems related with power quality such as voltage sag, voltage swell, voltage fluctuations (flicker), transient, harmonics distortion and etc. Power quality issues can be divided into short duration, long duration, and continuous categories. The computer industry has developed a qualification standard to categorize power quality events. The most common standard is the CBEMA curve (Computer Business Equipment Manufacturing Association). Other standards include ANSI and ITIC.

From literature study, most of proposals is about the detection and classification methods for PQ events. The classification of a PQ event is as important as its detection because a large class of events is due to the normal operation of power distribution networks, and these events should not cause nuisance tripping of protection equipment in the network.

On the other hand, arcing faults correspond to relatively dangerous cases and they must be opened by protective equipment in order to avoid undesirable consequences such as fire in the wiring conduits and complete loss of a delicate load. The following table 3.2 describes about several of the power quality events that usually occurs [20].

Table 3.2: Description of Power Quality Events

Power Quality Events	Description
Voltage Sags 	• Voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. • Voltage sag causes a problem will depend on the magnitude and duration of the sag and on the sensitivity of your equipment
Voltage Swell 	• Also known as Voltage Surge • The effects of a swell can often be more destructive than those of a sag. The overvoltage condition may cause breakdown of components on the power supplies of the equipment, though the effect may be a gradual, accumulative effect. The increase in output from incandescent lighting may be noticeable, if the duration is longer than three cycles.
Transient 	• Very quick < 1 cycle • Normal cause is lightning strike • No lights flicker • Also cause by capacitor switching
Harmonic Distortion 	• Harmonic distortion is found in both the voltage and the current waveform • Generated by electronic loads, also called non-linear loads drives

3.3 Phase II: Data Collection

The data of power quality events in this project was taken from TNB distribution in Skudai area at 22 kV. The data that contains harmonics distortion was observed and then analyzed by using RPM Power Analysis Software. Figure 3.3 below shows the location of TNB Distribution in Skudai, Johore, where the data was taken.

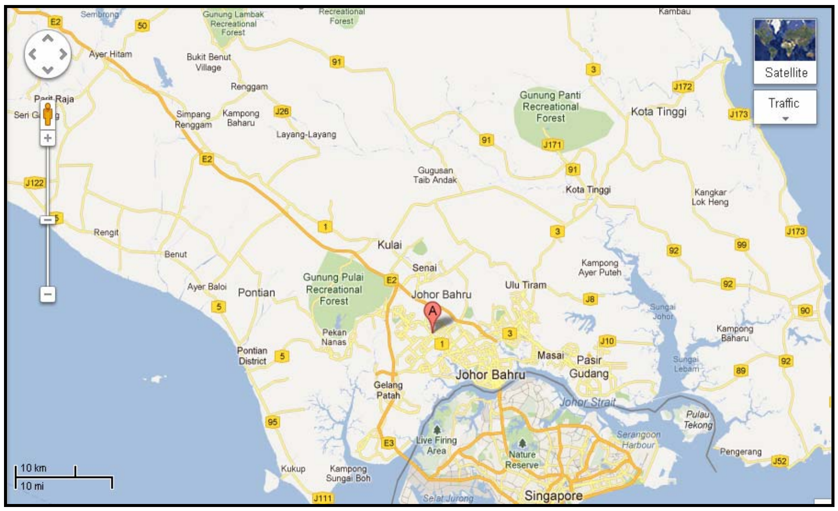


Figure 3.3: Location of TNB Distribution in Skudai, Johore

3.4 Phase III: Evaluate Data using Structural Equation Modeling

This method is a statistical technique for testing and estimating causal relations using a combination of statistical data and qualitative causal assumptions. Nowadays, Structural Equation Modeling (SEM) tools are increasingly being used in behavioral science research for the causal modeling of complex, multivariate data sets. The SEM model contains two inter-related models, which are the measurement model and the structural model. Both models are defines by the researcher. The measurement model defines the constructs (latent variables) that the model will use, and assigns observed variables to each. The structural model then defines the causal relationship among the latent variables. For this project, AMOS 5.0.1 software was used. The model for this project was constructed using Amos Graphics. Figure 3.4 below shows the flow chart of the steps done in performing SEM analysis.

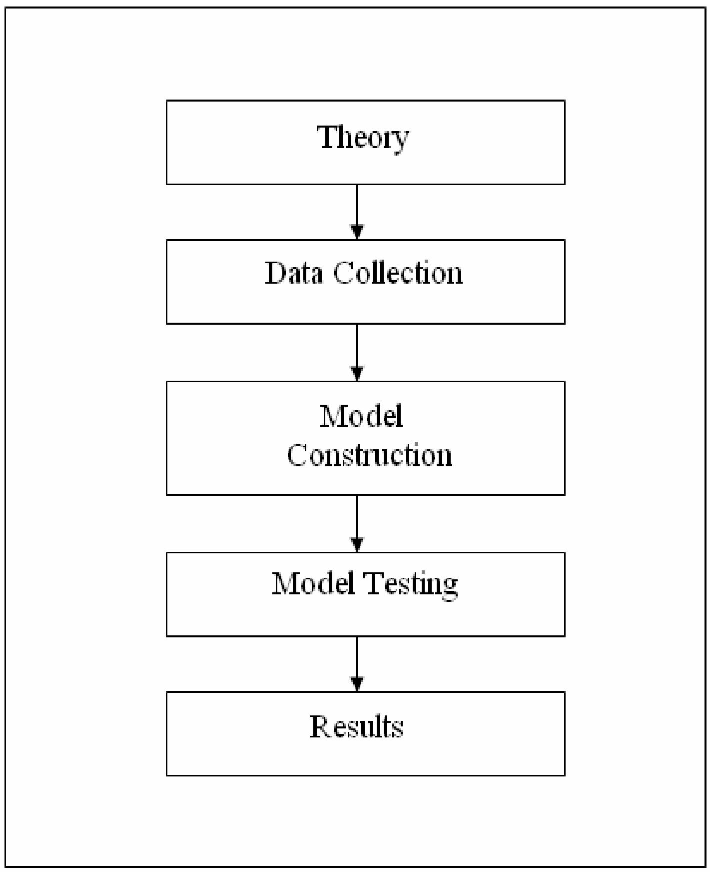
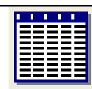
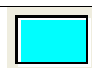
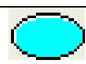
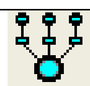
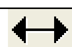
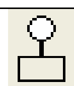
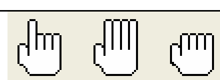
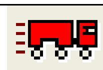
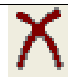
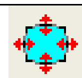
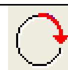
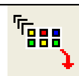
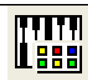
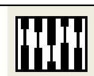
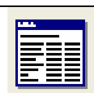


Figure 3.4: Flow Chart of SEM analysis

Based on the above flow chart, the theory of Structural Equation Modeling was first studied and then data was collected and analyzed using Power Analysis Software. Based on the data and the Total Harmonic Distortion (THD) formula, calculation was done in determining the percentage of THD. The data from the software was converted later to text file (*.txt) and excel (*.xls) file, and then inputs the data into the SEM software package. The package fits the data to the specified model and produces the results. There are several steps in performing model construction, model testing and observing results. The first steps are handling data manipulation and get the data into AMOS. And then, the model or diagram was drawn. The third and fourth step in SEM analysis is naming the variables and editing functions. Before running the model, the fifth step which is verifying analysis properties was done. And the sixth and last step done was running the model and viewing and observing the result. Table 3.4 below shows the icons and functions used in performing SEM analysis using AMOS Graphics.

Table 3.4: Icons and functions in performing SEM analysis using AMOS Graphics

Icons on AMOS 5.0.1	**Functions**
	Specify data files for the model
	View the variable list in the files user have specified
	Draws observed variables
	Draws latent variables. Also the symbol for error terms.
	Draws a latent variables with its indicators
	Causal relationships
	Covariances/correlations
	Adds an error term to an endogenous (dependent variable)
	Add a title to your diagram
	Select on object/select all objects/deselect all objects
	Copy object

	Move object
	Delete object
	Modify object size
	Rotate indicators of a latent variable
	Drag properties from one object to another
	Undo and Redo
	Analysis properties
	Calculate estimates/Run model
	View results (text form)

3.4.1 Total Harmonic Distortion

In understanding a system with an input and an output, such as an audio amplifier, it should be start with an ideal system where the transfer function is linear and time-invariant. When a signal passes through a non-ideal, non-linear device, additional content is added at the harmonics of the original frequencies. THD is a measurement of the extent of that distortion. When the input is a pure sine wave, the measurement is most commonly the ratio of the sum of the powers of all higher harmonic frequencies to the power at the first harmonic, or fundamental frequency.

$$\mathrm{THD} = \frac{P_2 + P_3 + P_4 + \cdots + P_\infty}{P_1} = \frac{\sum_{n=2}^{\infty} P_n}{P_1}$$

This can equivalently be written as

$$\mathrm{THD} = \frac{P_{\mathrm{total}} - P_1}{P_1}$$

If there is no source of power other than the signal and its harmonics.

Total harmonic distortion, or THD, is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave:

$$\mathrm{THD} = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2)}}{V_1} * 100\%$$

where V_n is the RMS voltage of nth harmonic and n=1 is the fundamental frequency
or

$$\mathrm{THD} = \frac{\sqrt{(I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2)}}{I_1} * 100\%$$

where I_n is the RMS current of nth harmonic and n=1 is the fundamental frequency

The formula above shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal. In this project, the formula above was used before performing model construction.

3.4.2 Root Mean Square Error of Approximation (RMSEA)

This measure, an absolute measure of fit, is based on the non-centrality parameter. Its formula can be shown to equal:

$$\sqrt{[\chi^2/df) - 1) / (N - 1)]}$$

where N the sample size and *df* the degrees of freedom of the model. (If χ^2 is less than *df*, then RMSEA is set to zero). First, the value of the non-centrality parameter is determined by χ^2- *df*. Then these values are substituted for χ^2- *df* into the formula for the RMSEA.

3.5 Phase IV: Evaluate Data using System Dynamic

System dynamics is a methodology and mathematical modeling technique for framing, understanding, and discussing complex issues and problems. System dynamics is an aspect of systems theory as a method for understanding the dynamic behavior of complex systems. The basis of the method is the recognition that the structure of any system. The elements of system dynamics diagrams are feedback, accumulation of flows into stocks and time delays. In this project, after the data is evaluated using Structural Equation Modeling, System Dynamic is used to evaluate the data and for that, another software was used which are Vensim PLE for Windows Version 5.11. The evaluation or analysis of the data involved several steps, which are:

- Define the problem boundary
- Draw a causal loop diagram
- Draw a stock and flow diagram

- Write the equations that determine the flows
- Estimate the parameters and initial conditions
- Simulate the model and analyze the results

Figure 3.5 shows the flow of system dynamic analysis done.

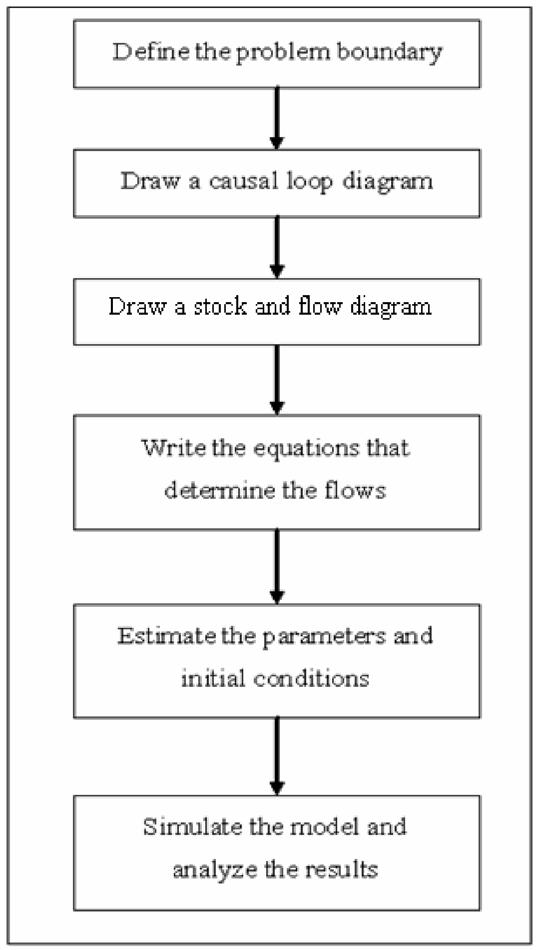


Figure 3.5: Flow of system dynamic analysis

3.6 Phase V: Results Comparing

In this stage, after evaluating the data using two methods, the results are compared and the best way to detect power quality events is justified. The results that have been obtained were explained in the next chapter.

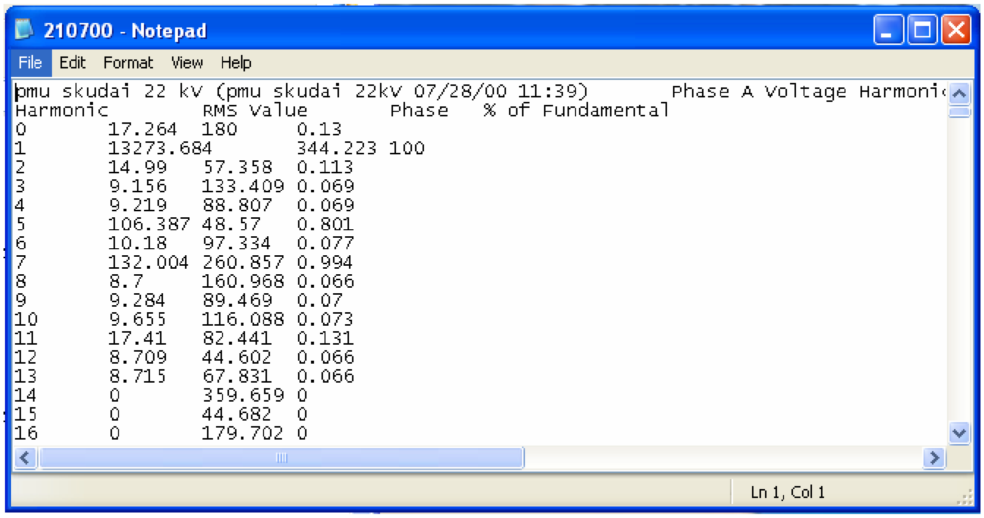
CHAPTER 4

RESULT AND ANALYSIS

This chapter discussed the result and analysis for this project. The analysis has been performed based on data obtained by the means of Structural Equation Modeling and System Dynamic method.

4.1 Structural Equation Modeling

Before SEM analysis was done, the data was converted to text file (*.txt) and excel file (*.xls) first. Figure 4.1 and 4.2 shows examples of the data in text and excel file.



210700 - Notepad

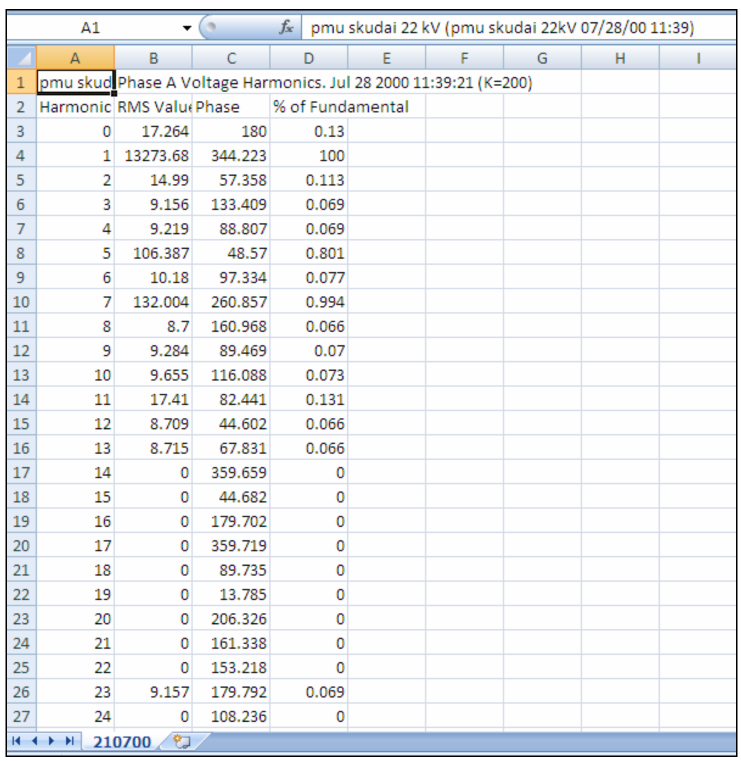
File Edit Format View Help

pmu skudai 22 kV (pmu skudai 22kV 07/28/00 11:39) Phase A Voltage Harmoni

Harmonic	RMS Value	Phase	% of Fundamental
0	17.264	180	0.13
1	13273.684	344.223	100
2	14.99	57.358	0.113
3	9.156	133.409	0.069
4	9.219	88.807	0.069
5	106.387	48.57	0.801
6	10.18	97.334	0.077
7	132.004	260.857	0.994
8	8.7	160.968	0.066
9	9.284	89.469	0.07
10	9.655	116.088	0.073
11	17.41	82.441	0.131
12	8.709	44.602	0.066
13	8.715	67.831	0.066
14	0	359.659	0
15	0	44.682	0
16	0	179.702	0

Ln 1, Col 1

Figure 4.1: Data in text file



A1 pmu skudai 22 kV (pmu skudai 22kV 07/28/00 11:39)

	A	B	C	D
1	pmu skud	Phase A Voltage Harmonics. Jul 28 2000 11:39:21 (K=200)		
2	Harmonic	RMS Valu	Phase	% of Fundamental
3	0	17.264	180	0.13
4	1	13273.68	344.223	100
5	2	14.99	57.358	0.113
6	3	9.156	133.409	0.069
7	4	9.219	88.807	0.069
8	5	106.387	48.57	0.801
9	6	10.18	97.334	0.077
10	7	132.004	260.857	0.994
11	8	8.7	160.968	0.066
12	9	9.284	89.469	0.07
13	10	9.655	116.088	0.073
14	11	17.41	82.441	0.131
15	12	8.709	44.602	0.066
16	13	8.715	67.831	0.066
17	14	0	359.659	0
18	15	0	44.682	0
19	16	0	179.702	0
20	17	0	359.719	0
21	18	0	89.735	0
22	19	0	13.785	0
23	20	0	206.326	0
24	21	0	161.338	0
25	22	0	153.218	0
26	23	9.157	179.792	0.069
27	24	0	108.236	0

210700

Figure 4.2: Data in excel file

SEM analysis was done on voltage and current harmonic distortion. Analysis was performed on each phase which is Phase A, Phase B and Phase C. Usually, in SEM diagrams the variables are arranged from left to right. Observed variables are represented by rectangles and unobserved variables are represented by ellipses.

4.1.1 Voltage harmonic distortion

4.1.1.1 Phase A

Figure 4.3 shows the waveform of Phase A Voltage Harmonic Distortion analyzed from Power Analysis Software.

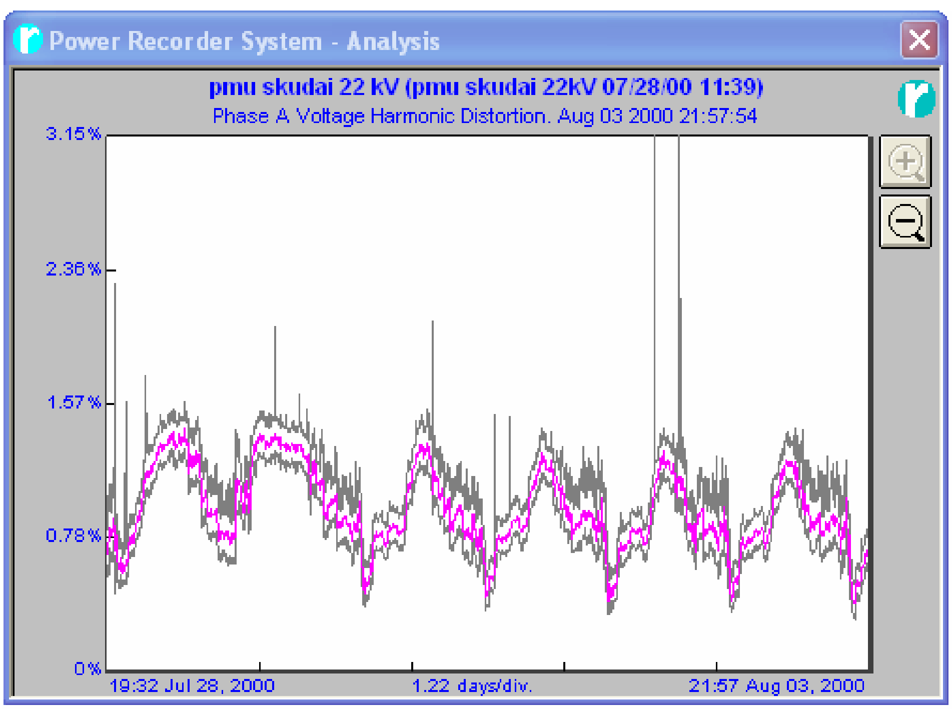


Figure 4.3: Waveform of Phase A Voltage Harmonic Distortion

Based on the Total Harmonic Distortion formula, the percentage of THD was calculated as below:

$$THD = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2)}}{V_1} * 100\%$$

$$= \frac{\sqrt{(14.99^2 + 9.156^2 + 9.219^2 + 106.387^2 + 10.18^2 + 132.004^2 + 8.7^2 + 9.284^2 + 9.655^2 + 17.41^2 + 8.709^2 + 8.715^2 + 9.157^2 + 12.757^2 + 36.035^2)}}{13.273k} \text{ X } 100\%$$

= **1.337 %**

From the calculation above, the percentage of total harmonic distortion is 1.337%. Figure 4.4 show the model constructed using AMOS Graphics.

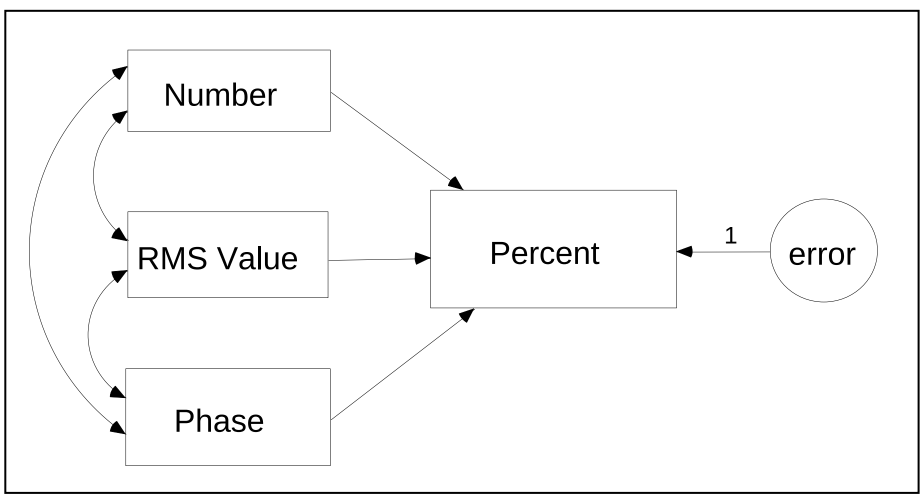


Figure 4.4: Model constructed

After the model was simulated, based on Root Mean Square Error of Approximation (RMSEA), the result obtained is **1.943**%.

REFERENCES

[1] Gefen,D., Straub,D., and Boudreau,M. (2000). Structural Equation Modeling and Regression:Guidelines for Research Practice. *Communications of AIS (7:7, August)*, pp.1-78.

[2] Romano,R. and Palumbo,F. (2006). Classification of structural equation models based on fuzzy regression. *Preprint submitted to KNEMO Conference 21 July 2006*, pp.1-17.

[3] Saghaei,A. and Ghasemi,R. (2009).Using Structural Equation Modeling in Causal Relationship Design for Balanced-Scorecards Strategic Map. *World Academy of Science, Engineering and Technology 49 2009*, pp.1-7.

[4] Shimizu,S. and Kano,Y. (2006). Use of non-normality in structural equation modeling: Application to direction of causation. *Preprint submitted to Elsevier Science 7 January 2006*, pp.1-18.

[5] Maxwell,K.H. (2007). *Structural Equation Modeling with Amos: A methodology for predicting behavioral intentions in the services sector*. Wisconsin: SPSS Inc.

[6] Gillespie,R.B., Hoffman,M.B. and Freudenberg,J. (2003). Haptic Interface for Hands-On Instruction in System Dynamics and Embedded Control. *Symposium 2003*, pp.1-6.

[7] Pruyt,E. (2004). System Dynamic Models of Electrical Wind Power. *MOSI Working Paper 2004*, pp.1-31.

[8] Lan,Z., Gan,D., Shi,L. and Ni,Y. (2007). A Study on the Control of AC/DC Power Systems Based on System Dynamic COI. pp.1-5.

[9] Ford,A. (1996). System Dynamics and the Electric Power Industry. *Jay Wright*

Forrester Prize Lecture 1996, pp.1-29.

[10] Kirkwood,C.W. (1998). *System Dynamics Methods: A Quick Introduction.* Arizona: Ventana Systems, Inc. pp.1-4.

[11] Chandrasekaran,K., Vengkatachalam,P.A, Karsiti,M.N. and Rao,K.S.R. (2007). Mitigation of Power Quality Disturbances. *Journal of Theoretical and Applied Information Technology*, pp.1-12.

[12] Haibo,H., Shen,X. and Starzyk,J.A. (2009). Power quality disturbances analysis based on EDMRA method. *Electrical Power and Energy Systems 31, 2009,* pp.258–268.

[13] El-Gammal,M., Abou-Ghazala,A. and El-Shennawy,T. (2003). Detection, localization, and classification of power quality disturbances using discrete wavelet transform technique. *Alexandria Engineering Journal, Vol. 42 (2003), No. 1, 17-23,* pp.1-7.

[14] Ece,D.G. and Gerek,O.N. (2004). Power Quality Event Detection Using Joint 2-D-Wavelet Subspaces. *IEEE Transactions on Instrumentation and Measurement, Vol.53, No.4, August 2004,* pp.1-7.

[15] Duque,C.A., Ribeiro,M.V., Ramos,F.R. and Szczupak,J. (2005). Power Quality Event Detection Based on the Divide and Conquer Principle and Innovation Concept. *IEEE Transactions on Power Delivery, Vol.20, No.4, October 2005*, pp.1-9.

[16] Ece,D.G. and Gerek,O.N. (2006). Power Quality Event Analysis Using Higher Order Cumulants and Quadratic Classifiers. IEEE Transactions on Power Delivery, Vol.21, No.2, April 2006, pp.1-7.

[17] Chen,C.I. and Fu,Y.T. (2010). Hybrid Power Quality Events Detection Method with Wavelet and ADALINE. *2010 International Conference on Power System Technology,* pp. 1-8.

[18] Sushama,M., Ram,G.T. and Laxmi,A.J. (2010). Detection on Power Quality Disturbances Using Wavelet Transforms. *International Journal of the Computer, the Internet and Management, Vol.18, No.1, January-April 2010,* pp.1-6.

[19] Montero-Hernández,O.C. and Enjeti,P.N. (2005). A Fast Detection Algorithm Suitable for Mitigation of Numerous Power Quality Disturbances. *IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 41, NO. 6, NOVEMBER/DECEMBER 2005*, pp.1-7.

[20] Gowan,C. and Loomis,C. (2006). *Power Quality and Harmonics: Causes, Effects and Remediation Techniques*, Cornell University